5   UTILITY APPLICATION

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          SOFT-REFERENCE THREE CONDUCTOR MAGNETIC MEMORY STORAGE
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SOFT-REFERENCE THREE CONDUCTOR MAGNETIC MEMORY STORAGE DEVICE

FIELD OF THE INVENTION

5 **[0001]** This invention relates generally to magnetic memory devices and in particular to soft-reference layer magnetic random access memory (commonly referred to as "MRAM") in a three conductor architecture.

BACKGROUND

10 **[0002]** Today's computer systems are becoming increasingly sophisticated, permitting users to perform an ever increasing variety of computing tasks at faster and faster rates. The size of the memory and the speed at which it can be accessed bear heavily upon the overall speed of the computer system.

15 **[0003]** Generally, the principle underlying the storage of data in magnetic media (main or mass storage) is the ability to change and/or reverse the relative orientation of the magnetization of a storage data bit (i.e. the logic state of a "0" or a "1"). The coercivity of a material is the level of demagnetizing force that must be applied to a magnetic particle to reduce and/or reverse the magnetization of the particle. Generally speaking, the smaller the 20 magnetic particle, the higher its coercivity.

[0004] A prior art magnetic memory cell may be a tunneling magneto-resistance memory cell (TMR), a giant magneto-resistance memory cell (GMR), or a colossal magneto-resistance memory cell (CMR). These types of magnetic memory are commonly referred to as spin valve memory cells (SVM). FIGS. 1A and 1B provide a perspective view 25 of a typical prior art magnetic memory cell having two conductors.

[0005] As shown in prior art FIG. 1A and 1B, a magnetic spin valve memory (SVM) cell **101** generally includes a data layer **103** which may alternatively be called a storage layer or bit layer, a reference layer **105**, and an intermediate layer **107** between the data layer **103** and the reference layer **105**. The data layer **103**, the reference layer **105**, and the 30 intermediate layer **107** can be made from one or more layers of material. Electrical current and magnetic fields may be provided to the SVM cell **101** by an electrically conductive row conductor **109** and an electrically conductive column conductor **111**. It is understood and appreciated that, as used herein, the terms row and column conductor have been selected for ease of discussion. Under appropriate circumstances these labels may be reversed and/or 35 otherwise substituted for such titles as word line and bit line.

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[0006]   The single SVM cell shown in FIGS. 1A and 1B are typically combined with other substantially identical SVM cells. In a typical MRAM device, the SVM cells are arranged in a cross-point array. Parallel conductive columns (column 1, 2, 3...), also referred to as word lines, cross parallel conductive rows (row A, B, C...), also referred to as bit lines. The traditional principles of column and row arrays dictate that any given row will only cross any given column once.

[0007]   An SVM cell is placed at each intersecting cross-point between a row and a column. By selecting a particular row (B) and a particular column (3), any one memory cell positioned at their intersection (B, 3) can be isolated from any other memory cell in the array. Such individual indexing is not without complexities.

[0008]   The data layer 103 is usually a layer of magnetic material that stores a bit of data as an orientation of magnetization M1 that may be altered in response to the application of an external magnetic field or fields. More specifically, the orientation of magnetization M1 of the data layer 103 representing the logic state can be rotated (switched) from a first orientation, 117 in FIG. 1A, representing a logic state of "0", to a second orientation, 119 in FIG. 1B representing a logic state of "1", and/or vice versa.

[0009]   The reference layer 105 is usually a layer of magnetic material in which an orientation of magnetization M2 is "pinned", as in fixed, in a predetermined direction, 121. The direction is predetermined and established by conventional microelectronic processing steps employed in the fabrication of the magnetic memory cell.

[0010]   The data layer 103 and reference layer 105 may be thought of as stacked bar magnets, each long on an X axis 113 and short on a Y axis 115. The magnetization of each layer has a strong preference to align along the easy axis, generally the long X axis 113. The short Y axis 115 is generally the hard axis. As with traditional bar magnets, the data layer and reference layer each have magnetic dipoles - North (N) and South (S) - one at either end of the easy axis. The lines of magnetic force that surround the data layer and reference layers are three-dimensional and flow from the North to the South pole.

[0011]   Typically, the logic state (a "0" or a "1") of a magnetic memory cell depends on the relative orientations of magnetization M1 in the data layer 103 and M2 of the reference layer 105, 117 to 121 as shown in FIG. 1A or 119 to 121 as shown in FIG. 1B. For example, when an electrical potential bias is applied across the data layer 103 and the reference layer 105 in an SVM cell 101, electrons migrate between the data layer 103 and the reference layer 105 through the intermediate layer 107. The intermediate layer 107 is

typically a thin dielectric layer, which is commonly referred to as a tunnel barrier layer. The phenomenon that cause the migration of electrons through the barrier layer may be referred to as quantum mechanical tunneling or spin tunneling.

[0012]   The logic state may be determined by measuring the resistance of the SVM cell 101. For example, if the orientation **119** of the magnetization M1 in the data layer **103** is parallel to the pinned orientation **121** of magnetization in the reference layer **105** the magnetic memory cell will be in a state of low resistance, R, see FIG. 1B. If the orientation **117** of the magnetization M1 in the data layer **103** is anti-parallel (opposite) to the pinned orientation **121** of magnetization in the reference layer **105**, the magnetic memory cell will be in a state of high resistance, R + ? R, see FIG. 1A. The orientation of M1 and, therefore, the logic state of the SVM cell **101** may be read by sensing the resistance of the SVM cell **101**.

[0013]   In an ideal setting, the orientation **117, 119** of the alterable magnetic field M1 in the data layer **103** is be either parallel or anti-parallel with respect to the set orientation **121** of magnetic field M2 of the reference layer **105**. It is problematic that as both the data layer **103** and the reference layer **105** are generally made from ferromagnetic materials and are positioned in close permanent proximity to each other The pinned reference layer **105** may affect the orientation of the data layer **103**. More specifically, the magnetization M2 of the reference layer **105** may generate a demagnetization field that extends from the reference layer **105** into the data layer **103**.

[0014]   The result of this demagnetization field from the reference layer **105** is an offset in the coercive switching field. This offset can result in asymmetry in the switching characteristics of the data layer **103** and the amount of switching field needed to switch the bit from parallel to anti-parallel state differs from the amount of switching field needed to switch the bit from anti-parallel state to parallel state.   To achieve reliable switching characteristics and to simplify the read/write circuitry, it is desirable to reduce this offset to as near zero as possible.

[0015]   The magneto-resistance ? R/R ratio is analogous to a signal-to-noise ratio S/N in that a higher S/N or magneto-resistance ratio results in a stronger signal that can be sensed to determine the state of the bit in the data layer. Thus, at least one disadvantage of a tunnel junction memory cell having a pinned reference layer in close and fixed proximity to the data layer is a potential reduction in the magneto-resistance ? R/R resulting from the angular displacement.

[0016]   The pinned nature of the pinned reference layer is typically established with the use of anti-ferromagnetic (AFM) material in direct physical contact with a ferromagnetic (FM) material. AFM materials magnetically order below their Neel temperatures (T_N), the temperature at which they become anti-ferromagnetic or anti-ferrimagnetic. The Neel temperature of AFM materials is analogous to the Curie Temperature (T_C) of FM materials, the temperature above which a FM loses its ability to possess an ordered magnetic state in the absence of an external magnetic field. Generally T_C of the FM is greater than T_N of the AFM.

[0017]   With respect to a traditional bar magnet there are two equally stable easy spin directions (each rotated 180 degrees) along the easy axis, generally the longer axis of the magnet – the shorter axis being the hard axis. Alignment in either direction requires the same energy and requires the same external field to align the spin of the atomic particles and thus the magnetic field, in either direction.

[0018]   In establishing a reliable pinned field, it is desirable to establish a preferred orientation along one direction of an axis, typically the easy axis although in some situations it may be the hard axis. By growing the FM on an AFM in a magnetic field H or annealing in field H at a temperature above the Neel temperature of the AFM, the hysteresis loop (FM + AFM + H) becomes asymmetric and is shifted. In general, this shift is significantly greater than H, on the order of a couple hundred Oe. This unidirectional shift is called the exchange bias and demonstrates that there is now a preferred easy axis alignment direction.

[0019]   The annealing step typically takes time, perhaps an hour or more. In the annealing step the reference layer is heated to a temperature greater than T_N while a magnetic field is applied. As the reference layer is but one part of the memory being produced, the entire memory is typically subjected to temperatures ranging from about 200 to 300 degrees. As the temperature is lowered through T_N, the spin of the AFM molecules at the interface between the AFM and FM layers will order and couple to the aligned FM spin. Such ordering of the AFM exerts a torque upon the FM material and results in establishing the pinned orientation of the reference layer.

[0020]   As a result of such manufacturing stress, the reference layer may un-pin and lose its set orientation if the memory is later subjected to high temperatures. In addition, the characteristics of the data layer may be unknowingly affected by heat during some manufacturing processes.

[0021]   The traditional process of reading the stored bit is somewhat undesirable, although effective. In general, the row conductor 109 and column conductor 111 for a given SVM cell 101 are selected by appropriate control logic. The control logic is generally further responsible for applying a sense current through the selected column conductor 111 and row conductor 109, measuring the resistance of the current through the SVM cell 101, and recording the measured resistance value. Next, a larger write current is applied to put the data layer 103 into a known orientation. Then, a sense current is re-applied and the resistance of the SVM cell 101 is measured again.

[0022]   The value determined from a known orientation (the second sense) is then compared with the value from the initial condition (the first sense). The values will either be the same or different, permitting a determination of the data value. If necessary, such as where the initial position is determined to be opposite to the known orientation, a write back can be performed to restore the original initial value. This process is a self reference process and is known as double sampling – the first sample being the initial read and the second being after the known orientation write.

[0023]   Multiple variations of self reference sampling may be performed with double sampling; however, the underlying negative aspect remains unchanged, namely, to determine the value stored in the data layer 103, it is necessary to change the value in the data layer 103. This change for the purpose of sensing introduces a significant element of risk in data corruption should an error occur during the repetitive sense and write operations.

[0024]   As a traditional sense operation involves the re-writing the data layer 103 of the SVM cell 101, the physical design of the SVM cell 101 is typically dictated by the stresses imposed by the write process, as both the sense and write operations are performed using the same row and column conductors 109 and 111. As the write magnetic field is typically generated by current applied to the row and column conductors 109 and 111, which are in electrical contact with the SVM cell 101, it is desirable for the SVM cell 101 to be robust enough to withstand the applied current. Design and manufacturing issues are therefore generally focused upon the requirements imposed by the write operation, such as greater electrical current and magnetic fields, higher applied voltages, more robust characteristics in the power supply, row and column conductors 109 and 111 and appropriate buffering spaces.

[0025]   With respect to magnetic memory components, it is well known that as size decreases, coercivity increases. A large coercivity is generally undesirable, as it must be

switched using a greater magnetic field. In turn, a greater magnetic field requires a greater power source and may require larger switching transistors and conductors. Providing large power sources and large switching transistors is generally at odds with industry requirements to reduce the size of nano-scaled components.

[0026] In addition, to mitigate the possibility of inadvertently switching a neighboring memory cell, nanometer scaled memory cells are generally more widely spaced relative to their overall size than are larger, non-nanometer sized memory cells. Moreover, as the size of the magnetic memory decreases, the unused buffering space between individual memory cells tends to increase. Eliminating this buffering space, or otherwise reducing its ratio, may provide a greater volume of storage in the same physical space.

[0027] These issues of read vs. write currents, robustness of conductors and power supplies, reduction in size increasing coercivity and resulting in a correspondingly greater magnetic field, and current design of the magnetic memory cells also carry over into the design and use of magnetic field sensors. Magnetic field sensors are commonly used in hard drive read cells and read heads. In such implementation, the data layer 103 is termed a sense layer. Whereas the orientation M1 of a data layer in an MRAM cell is generally established by a magnetic field provided by the row and column conductors, the orientation M1 of a sense layer in a read head is generally established by a magnetic field emanating from a storage bit proximate to the read head.

[0028] Hence, there is a need for an ultra-high density magnetic memory which overcomes one or more of the drawbacks identified above.

SUMMARY

[0029] The present disclosure advances the art and overcomes problems articulated above by providing a soft-reference three-conductor magnetic memory storage device.

[0030] In particular, and by way of example only, according to an embodiment a soft-reference three conductor magnetic memory storage device includes: an electrically conductive first sense/write conductor; an electrically conductive second sense conductor; a soft-reference SVM cell in electrical contact with and located between the first sense/write conductor and the second sense conductor, the memory cell including a material with an alterable orientation of magnetization; and an electrically conductive third write column conductor substantially proximate to and electrically isolated from the second sense conductor.

[0031]   In yet another embodiment, provided is a method of self referenced, non-destructively determining a data value in a magnetic memory storage device having a plurality of soft-reference layer three conductor SVM cells, each cell including at least one data layer and at least one soft-reference layer, the method including: selecting a given SVM cell in electrical contact with a given first sense/write conductor, a given second sense conductor, and substantially proximate to and electrically isolated from a third write column conductor; providing an initial field current to the third write column conductor; the initial current generating an initial sense magnetic field proximate to the given SVM cell; pinning-on-the-fly the soft-reference layer of the given SVM cell in orientation with the initial sense magnetic field; providing an initial sense current by the given first sense/write conductor and second sense conductor through the given SVM cell; measuring an initial resistance value of the given SVM cell; storing the initial resistance value; providing a second known field current to the third write column conductor, the second known current generating an second known sense magnetic field orienting the soft-reference layer in a second known orientation; providing a second sense current by the given first sense/write conductor and second sense conductor through the given SVM cell; storing the second resistance value as a reference resistance; comparing the initial resistance value to the reference resistance value; and returning a logic level associated with the compared state.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032]   FIGS. 1A ~ 1B show perspective views of a prior art magnetic memory cell having two conductors;

[0033]   FIG. 2A provides a plain view of a soft-reference three conductor magnetic memory according to one embodiment;

[0034]   FIG. 2B provides a plain view of a soft-reference three conductor magnetic memory according to an alternative embodiment;

[0035]   FIG. 2C provides a plain view of a soft-reference three conductor magnetic memory according to yet another alternative embodiment;

[0036]   FIG. 3 provides plain views of the memory according to FIG. 2A;

[0037]   FIG. 4A is a partial perspective view of the cross-point array of the memory of FIG. 3A;

[0038]   FIG. 4B illustrates the switching model of the memory of FIGS. 2A through 4A;

[0039]   FIGS. 5A and 5B show partial perspective views of the memory of FIG. 2A with respect to the generated sense magnetic fields;

[0040]   FIGS. 6A and 6B show partial perspective views of the memory of FIG. 2A with respect to the generated write magnetic fields;

[0041]   FIG. 7 is a flowchart depicting the steps of non-destructively sensing the data value within the memory according to FIGS. 2A, 5A and 5B.

DETAILED DESCRIPTION

5   [0042]   Before proceeding with the detailed description, it is to be appreciated that the present teaching is by way of example, not limitation. The concepts herein are not limited to use or application with a specific type of magnetic memory. Thus, although the instrumentalities described herein are for the convenience of explanation, shown and described with respect to exemplary embodiments, it will be appreciated that the principals

10   herein may be equally applied in other types of magnetic memory.

[0043]   Referring now to the drawings, and more particularly to FIG. 2A, there is shown a portion of a soft-reference three-conductor magnetic memory 200 having at least one soft-reference spin valve magnetic memory (SVM) cell 202. In at least one embodiment, the memory cell 202 is a soft-reference SVM cell 202 having an electrically

15   conductive first sense/write conductor 204, an electrically conductive second sense conductor 206 and an electrically conductive third write column conductor 208.

[0044]   The soft-reference SVM cell 202 has a ferromagnetic data layer 210, an intermediate layer 212 and a ferromagnetic soft-reference layer 214. The ferromagnetic data layer 210 permits the storing of a bit of data as an alterable orientation of magnetization

20   M1 220. The intermediate layer 212 has opposing sides such that the data layer 210 in contact with one side is in direct alignment with, and substantially uniformly spaced from, the soft-reference layer 214, in contact with the second side of the intermediate layer 212. The soft-reference layer 214 is characterized by a non-pinned orientation of magnetization M2 222 and a lower coercivity than the data layer 210.

25   [0045]   The data layer 210 is typically established with the use of a ferromagnetic (FM) material layer. Unlike a pinned reference layer, the FM layer is generally not provided in contact with an anti-ferromagnetic (AFM) layer as it is generally not necessary to establish a magnetic exchange bias. The hysteresis loop of the data layer 210 is substantially symmetric, indicating two substantially equivalent easy directions for magnetic alignment.

30   [0046]   The magnetic orientation M1 220 of the data layer 210 can be oriented in a chosen direction along generally the easy axis when an appropriate magnetic field is applied, and remain in that orientation when the field is removed. More specifically the orientation M1 220 is set by applying a magnetic field that overcomes the coercivity of the

data layer **210**, Hc(data). In short, the magnetic orientation M1 **220** of the data layer **210** is alterable, but will be maintained in the last state of orientation.

[0047]   In contrast to the prior art pinned reference layer, a soft-reference layer **214** is established by providing a FM layer that is not in direct contact with an AFM layer. The coercivity of the soft-reference layer **214**, Hc(sref), is substantially minimal. Moreover, in the presence of a magnetic field with a magnitude greater than Hc(ref), the coercivity of the soft-reference layer **214** will be overcome and the orientation M2 **222** of the soft-reference layer **214** will align to the field. The soft-reference layer **214** is therefore similar to the data layer **210** in having the ability to orient in the presence of a magnetic field.

[0048]   The ferromagnetic data layer **210** and the soft-reference layer **214** may be made from a material that includes, for example: Nickel Iron (NiFe), Nickel Iron Cobalt (NiFeCo), Cobalt Iron (CoFe), and alloys of such metals. In at least one embodiment, the data layer **210** and soft-reference layer **214** are made from NiFe. One difference between the data layer **210** and the soft-reference layer **214** is that the coercivity of the soft-reference layer **214**, Hc(sref) is less than the coercivity of the data layer **210**, Hc(data). As such, the orientation M **222** of the soft-reference layer **214** may be oriented / re-oriented without disrupting the orientation M1 **220** of the data layer **210**. The difference in coercivity may be achieved by both shape, thickness, or composition of the data layer **210** and soft-reference layer **214**.

[0049]   In addition, both the soft-reference layer **214** and the data layer **210** may be formed from multiple layers of materials. Such formation from multiple layers may be desired, for example, to provide a more uniform magnetic structure than may be achieved by applying either a very thick or very thin layer of FM material. However, for conceptual simplicity and ease of discussion, each layer component is herein discussed as a single layer.

[0050]   As illustrated, in FIGS. 2A, 2B and 2C the third write column conductor **208** is substantially proximate to and electrically isolated from the second sense conductor **206**. In at least one embodiment, this electrical isolation may be accomplished by physical spacing **216**. Under appropriate circumstances, such isolation may be achieved with the use of a material such as a dielectric. In at least one embodiment this isolation is achieved with a dielectric between the third write column **208** and the second sense conductor **206**. More specifically, the third write column conductor **208** is not in electrical contact with the SVM cell **202**.

[0051]   The SVM cell **202** is located between and in electrical contact with the first sense/write conductor **204** and the second sense conductor **206**. More specifically, in at least one embodiment the first sense/write conductor **204** is in electrical contact with the data layer **210**, opposite from the intermediate layer **212**. Likewise, the second sense conductor **206** is in electrical contact with the soft-reference layer **214**, opposite from the intermediate layer **212**.

[0052]   In at least one alternative embodiment, this relationship is flipped. More specifically and as shown in FIG. 2B, the first sense/write conductor **204** is in electrical contact with the soft-reference layer **214** and the second sense conductor **206** is in electrical contact with the data layer **210**.

[0053]   In yet another embodiment, as shown in FIG. 2C, under appropriate circumstances the third write column conductor **208** and/or the first sense/write conductor **204** may be at least partially coated with ferromagnetic cladding **218** so as to concentrate the magnetic field in the data layer and minimize the spread of sense and write magnetic fields.

[0054]   FIG.3 conceptually illustrates a larger portion of the magnetic memory **200** wherein the plurality of SVM cells **202, 300, 302,** and **304** are arranged in a cross-point array (see FIG. 4). As shown, the cross-point array **400** includes a plurality of parallel electrically conductive first sense/write conductors **204** and **204'** (see FIG. 4 for **204'**). A plurality of electrically conductive second sense conductors **206, 306, 308,** and **310** cross the first sense/write conductors **204** and **204'**, thereby forming a cross-point array with a plurality of intersections.

[0055]   In at least one embodiment, first sense/write conductors (**204, 204'**) are transverse to the second sense conductors (**206, 306, 308, 310**). The first sense/write conductors (**204, 204'**) may be described as conductive rows or conductive word lines. The second sense conductors (**206, 306, 308, 400**) may be described as conductive columns or conductive bit lines.

[0056]   A plurality of soft-reference SVM cells **202, 300, 302,** and **304** are also provided. Respectively, each cell is in electrical contact with, and located at, an intersection between a given first sense/write conductor and a given second sense conductor. Moreover, the placement of each soft-reference SVM cell **202, 300, 302,** and **304** is substantially in alignment with the intersections of the cross-point array **400**.

[0057]   A plurality of electrically conductive third write column conductors **208, 312, 314,** and **316** are located substantially proximate to and electrically isolated from the second

sense conductors **206**, **306**, **308**, and **310**. As shown, in at least one embodiment the electrically conductive third write column conductors **208**, **312**, **314** and **316** are substantially parallel to and in alignment with the second sense conductors **206**, **306**, **308**, and **310**.

[0058]   FIG. 4A provides a perspective view of the cross-point array architecture illustrated in FIG. 3. The component structures of SVM cells **300**, **300'** and **202'** parallel those of SVM cell **202** as described above and illustrated in FIGS. 2 ~ 3. As shown, the third write column conductors **208** and **312** are substantially parallel to one another, and to the second sense conductors **206** and **306**. The electrical isolation of the write conductors **208** and **312** may also be more fully appreciated. Illustrated as physical space **216** isolation, under appropriate circumstances this electrical isolation may also be achieved with the use of a dielectric or other material which provides electrical isolation while permitting magnetic interaction.

[0059]   The behavior and properties of SVM memory cells are generally well understood. Three types of SVM cells in particular are known – a tunneling magneto-resistance memory cell (TMR), a giant magneto-resistance memory cell (GMR) and colossal magneto-resistance memory cell (CMR). GMR and CMR memory cells have similar magnetic behavior but their magneto-resistance arises from different physical effects as the electrical conduction mechanisms are different. More specifically, in a TMR-based memory cell, the phenomenon is referred to as quantum-mechanical tunneling or spin-dependent tunneling. In a TMR memory cell, the intermediate layer **212** is a thin barrier of dielectric material through which electrons quantum mechanically tunnel between the data layer **210** and the soft-reference layer **214**.

[0060]   In a GMR memory cell, the intermediate layer **212** is a thin spacer layer of non-magnetic but conducting material. Here the conduction is a spin-dependent scattering of electrons passing between the data layer **210** and the soft-reference layer **214** though the intermediate layer **212**. In either case, the resistance between the data layer **210** and the soft-reference layer **214** will increase or decrease depending on the relative orientations of the magnetic fields M1 **220** and M2 **222**. It is that difference in resistance that is sensed to determine if the data layer **210** is storing a logic state of "0" or a logic state of "1".

[0061]   In at least one embodiment, the SVM cell **202** is a TMR cell wherein the intermediate layer **212** is a tunnel layer made from an electrically insulating material (a dielectric) that separates and electrically isolates the data layer **210** from the soft-reference

layer **214**. Suitable dielectric materials for the dielectric intermediate layer **212** may include, but are not limited to: Silicon Oxide (SiO_2), Magnesium Oxide (MgO), Silicon Nitride (SiN_x), Aluminum Oxide (Al_2O_3), Aluminum Nitride (AlN_x), and Tantalum Oxide (TaO_x). In at least one embodiment, the intermediate layer **212** is Silicon Oxide.

[0062]   In at least one other embodiment, the SVM cell **202** is a GMR or CMR cell wherein the intermediate layer **212** is made from a non-magnetic material such as a *3d*, a *4d*, or a *5d* transition metal listed in the periodic table of the elements. Suitable non-magnetic materials for a non-magnetic intermediate layer **212** may include, but are not limited to: Copper (Cu), Gold (Au) and Silver (Ag). In at least one embodiment, the intermediate layer **212** is Copper.

[0063]   While the actual thickness of the intermediate layer **212** is dependent upon the materials selected to create the intermediate layer **212** and the type of tunnel memory cell desired, in general, the intermediate layer **212** has a thickness of about 0.5 nm to about 5.0 nm. However, under appropriate circumstances this thickness may be increased or decreased.

[0064]   The soft-reference layer **214** shown in FIGS. 2A through 4A is so named because the direction of orientation of magnetization M2 can be dynamically set. Such dynamic setting may be achieved by a magnetic field or fields provided by an externally supplied current flowing through at least one conductor. This dynamic setting may be referred to as pinned-on-the-fly, or even more appropriately, as oriented-on-the-fly, as is used herein.

[0065]   The use of a soft-reference layer **214** has several advantageous benefits in the SVM cell **202**. As a soft-reference layer is not substantially pinned in orientation, it may not be necessary to subject the SVM cell **202** to high temperatures during manufacturing, as is often required to establish a fixed/pinned reference layer. In addition, the lack of a substantial and constant magnetic field in the soft-reference layer **214** reduces the likelihood of a demagnetization field from the soft-reference layer **214** acting upon the data layer **210**, thus reducing the offset in the coercive switching field.

[0066]   Like magnetic dipoles (North – North) repel while opposite magnetic dipoles (North – South) attract. As a result of this natural behavior, the soft-reference layer **214** may be described as having an "at-rest" orientation of M2. When "at rest", the orientation of M2 **222** for the soft-reference layer **214** will be anti-parallel to the orientation of M1 **220**, for whichever direction along the easy axis M1 **220** has been set in the data layer **210**.

[0067]   This "at rest" relationship is illustrated in FIG. 3 and FIG. 4A, showing SVM cell **202** with an anti-parallel relationship between M1 **220** and M2 **222**, and SVM cell **300** with an anti-parallel relationship between M1 **318** and M2 **320**. The "at rest" state occurs when the only magnetic field substantially acting upon the soft-reference layer **214** is the magnetic field of the data layer **210**. Such an "at rest" condition also exists when the magnitude of a magnetic field proximate to the SVM cell **202** produced when a current is passed through a proximate conductor is substantially zero.

[0068]   The use of three conductors provides several advantages over the prior art for sensing and writing. The write operation is dependent upon a sufficient magnetic switching field being provided to overcome the coercivity of the data layer **210** and orient its magnetization M1 in a desired direction. This operation is not dependent upon the flow of current through the SVM cell **202**.

[0069]   As the third write column conductors **208** and **312** are electrically isolated from the second sense conductors **206** and **306**, and thus by implication electrically insulated from the SVM cells **202**, **202'**, **300**, **300'**, a greater voltage may be applied to the third write column conductors **208** and **312**. This greater voltage permits a greater current to be applied through the third write column conductors **208** and **312** than might otherwise be applied to the SVM cells **202**, **202'**, **300**, and **300'**. The purpose of the current in third write column conductors **208** and **312** is to generate a magnetic switching field. Providing at least one switching field without requiring the SVM cells **202**, **202'**, **300**, and **300'** to endure the requisite high current reduces the likelihood of fatigue and or failure of the SVM cells **202**, **202'**, **300**, and **300'** .

[0070]   Further, a magnetic switching field may be applied along either the hard axis, the soft axis or a combination of both. As illustrated in FIG. 4B, combining fields along the hard axis HA **450** and easy axis EA **452**, provides a "Stoner-Wohlfarth" asteroid switching model. The combined fields provide a switching field represented as asteroid **454**. An individual field or combined field that falls within the asteroid **454** is insufficient to overcome the coercivity of a particle, whereas an individual or combined set of fields falling on or outside the asteroid **454** will overcome the coercivity of the particle. More specifically, point **456** represents a combined field sufficient to overcome the coercivity of a particle and align it to the "1" orientation, at a point where the individual fields would be insufficient on their own.

[0071]   The third write column conductor **208** provides a write magnetic field to the data layer **210** along the easy axis, which by itself is insufficient to overcome the coercivity of the data layer **210** and orient M1. However, working in tandem with the first sense/write conductor **204** providing an additional write magnetic field along the hard axis, the combined magnetic fields will suffice to overcome the coercivity of the data layer **210**. The effect of the combined magnetic field upon the soft-reference layer **214** is of substantially no concern, as the soft-reference orientation M2 is not fixed and will respond again when an appropriate sense field is applied

[0072]   The use of a combined field advantageously reduces the possibility of inadvertent half-select write errors – instances where unintended cells are inadvertently re-oriented as well.   In the absence of the additional current from the first sense/write conductor **204**, or by utilizing a lower current, the third write column conductor **208** orients the soft-reference layer **214** on-the-fly.

[0073]   In addition, the use of a soft-reference layer **214** within the three-conductor architecture permits the determination of the data bit stored in the data layer **210** without destructively over-writing and re-writing the data bit. As such, a substantial opportunity for inadvertent data corruption is advantageously avoided.

[0074]   More specifically, during a read operation the ferromagnetic soft-reference layer **214** is oriented-on-the-fly to a desired orientation by a sense magnetic field generated by at least one sense current flowing in the third write column conductor **208**.   This generated magnetic field is insufficient to affect the orientation of the data layer **210**.

[0075]   It is to be understood that the arrangements illustrated in FIGS. 2 through 6 have has been provided for the ease of conceptual illustration.   Under appropriate circumstances the parallel relationships between the third write column conductor and the second sense conductor may not be employed. In addition, the depiction of the SVM cells, data layers, intermediate layers, soft-reference layers, first sense/write conductors, second sense conductors, and third write column conductors as rectangular structures is not intended to suggest or imply that they will take this form in each embodiment. It is further appreciated that the drawings are not to scale.

[0076]   Having described the above physical embodiment of the soft-reference three conductor magnetic memory **200**, another embodiment relating to the method of use in non-destructively determining the value held in the data layer **210** will now be described with reference to FIGS. 5A – 5B and 6A – 6B, illustrating a cross-point array, and the Flowchart

of FIG. 7. It will be appreciated that the described method need not be performed in the order in which it is herein described, but that this description is merely exemplary of at least one method of using soft-reference three-conductor magnetic memory **200**, in accordance with the present instrumentality. Except for the first "2" in the reference numerals used in the Figures above, the remainder of the numerals in FIGS 5A ~ 6B follow those used in other Figures, to indicate similarity.

[0077]   As indicated in the flowchart of FIG. 7, the selection of a given magnetic memory cell is made in step **700** from a storage device having a plurality of soft-reference three-conductor magnetic memory cells. The selection is accomplished with the appropriate control logic. Such control logic may, for example, include row and column selectors switchably connecting to the appropriate conductors proximate to the selected SVM cell. More specifically, FIGS. 5A and 5B conceptually illustrate the perspective view of a selected SVM cell **502**, substantially similar to SVM cell **202**, described above.

[0078]   As shown, SVM cell **502** has at least one ferromagnetic data layer **510**, an intermediate layer **512** and a ferromagnetic soft-reference layer **514**. The ferromagnetic data layer **510** permits the storing of a bit of data as an alterable orientation of magnetization M1. The intermediate layer **512** has opposing sides such that the data layer **510** in contact with one side is in direct alignment with, and substantially uniformly spaced from, the soft-reference layer **514**, in contact with the second side of the intermediate layer **512**. The soft-reference layer **514** is characterized by a non-pinned orientation of magnetization M2 and a lower coercivity than the data layer **510**.

[0079]   The perspective cross section as shown illustrates the soft-reference three conductor magnetic memory **200** in a cross-point architecture. The first sense/write conductor **504** is in electrical contact with the data layer **510**, and is substantially transverse to the second sense conductor **506** in electrical contact with the soft-reference layer **514**. The third write column conductor **508** is substantially proximate to, and electrically isolated from, the second sense conductor **506**. In at least one embodiment the electrical isolation is provided by physical space **516**.

[0080]   In a relaxed state where no current is applied, i.e. the magnitude of the current is substantially about zero, the orientation of M2 of the soft-reference layer **514** will be anti-parallel to the orientation M1 of the data layer **510**. This is due to the principles of magnetic coupling. Simply stated, the North pole of a magnet is attracted to the South pole of another magnet, and vice versa.

[0081] As the soft-reference layer **514** has no fixed orientation, when no other magnetic fields are present and over-riding, it will align itself to be opposite to the data layer **510**, thus providing its North pole to the data layer **510** South pole, and its South pole to the data layer **510** North Pole. This anti-parallel relaxed state orientation is unaffected by the SVM cell **502** being placed in proximity to other SVM cells, as for example in a cross-pint array.

[0082] With an SVM cell selected within the cross-point array, an initial sense current is provided. This initial sense current, and subsequent current may be provided and controlled by appropriate control logic, not shown. The initial sense current may be described as having at least two components – I_S which serves to generate the magnetic field and orient the soft-reference layer (blocks **702** and **704**), and I_R which passes through the SVM cell **502** and permits the measurement of resistance, blocks **706** and **708**. As shown in FIGS. 5A and 5B, the I_S component is applied through the third write column conductor **508** and the I_R component is applied through the first sense/write conductor **504** and second sense conductor **506**.

[0083] The separation of components into two distinct sense currents is, in at least one embodiment, advantageous. As the I_S component may be driven by a much larger voltage potential, the separation permits the first sense/write conductor **504**, the second sense conductor **506** and the SVM cell **502** to be fabricated without undue concern for an ability to withstand a large voltage potential. In at least one embodiment, the initial I_S current is substantially low. As such, the I_R component permits the resistance to be measured while M2 is substantially in its relaxed, natural, anti-parallel state with respect to M1.

[0084] The resistance of the SVM cell **502** is measured and recorded as "R1" indicated in blocks **708** and **710**. The initial I_S current provided may be applied in an arbitrary direction that is not immediately known. The initial I_S current provided may be substantially low, such that its magnitude is effectively zero and it does not orient-on-the-fly the soft-reference layer **514**. As such, though an initial resistance level R1 may be obtained, it is generally beneficial to provide a reference for comparison, and a local reference or self reference is preferred. Such a reference value may be advantageously obtained without disrupting the orientation M1 of the data layer **510**, simply by applying the I_S current in a Second Known Direction as indicated in block **712**.

[0085] As indicated in blocks **712** through **718** the resistance value from the Second Known Direction (the second resistance, R2) is measured and recorded as a reference

resistance. More specifically, as indicated in block **712** a second sense current I_S is provided to the third write column conductor flowing in a known direction. In at least one embodiment this known direction is opposite to the current flow of the initial I_S current.

[0086] As shown in FIG. 5A the sense current I_S is flowing into the page, indicated by the "+" symbol, such that the magnetic field (represented by curved arrows **550**) has a vector in the clockwise direction in accordance with the right-hand rule. The orientation of M2 of soft-reference layer **514** is therefore oriented-on-the-fly towards the left. The magnetic field **550** is by design quite small (within the asteroid **454** of FIG. 4B), and insufficient to affect the orientation of M1 of the data layer **510**.

[0087] Substantially contemporaneously with the generation of the magnetic field in the known direction, a second sense current I_R2 is applied to the first sense/write conductor and second sense conductor so as to permit the current I_R2 to flow through SVM cell **502**. In at least one embodiment I_R2 is substantially identical to I_R. The resistance, R2 of the current I_R2 is measured and recorded, blocks **716** and **718**.

[0088] With a reference resistance now known, the initial resistance may be compared. As illustrated in decision block **720**, if the initial resistance is different from the reference resistance (R1 > R2), a first logic level associated with this first state is returned, block **722**. If the initial resistance is not different (R1 = R2), then a second logic level associated with this second state is returned, block **724**.

[0089] This method advantageously permits the determination of the orientation of M1 within the data layer **510** in a non-destructive manner. In addition, there is advantageously no need to perform a write-back operation to reset the initial condition of M1, as it has not been changed. Eliminating a potential operation permits the soft-reference three conductor magnetic memory **200** to operate more quickly in situations that would otherwise require a write-back operation.

[0090] Under appropriate circumstances, a slightly different approach to sensing the data value may be taken. Briefly stated, the soft-reference layer is pinned-on-the-fly in two known directions, with the resistance being measured for each. The measured resistance values are then compared to determine the orientation of M1 in the data layer.

[0091] For example, and with respect to FIGS. 5A and 5B, an initial current I_S is applied in a First Known Direction to the third write column conductor **508**. As shown in FIG. 5A, the sense current I_S is flowing into the page, indicated by the "+" symbol, such that the magnetic field **550** has a vector in the clockwise direction in accordance with the right-

hand rule. The orientation of M2 **560** of the soft-reference layer **514** is therefore oriented-on-the-fly towards the left. The magnetic field **550** is by design small, and insufficient to affect the orientation of M1 **570** of the data layer **510**.

[0092] As the third write column conductor **508** is electrically isolated from the SVM cell **502** by intention, a separate initial current I_R is applied to the second sense conductor **506** to flow through the SVM cell **502** to first sense/write conductor **504**. The resistance from the First Known Sense Current (the first resistance, R1) is then measured and recorded as a reference resistance.

[0093] As shown in FIG. 5B, a current I_S is then applied to the third write column conductor **508** in a Second Known Direction. As shown in FIG. 5B, the sense current I_S is flowing out of the page, indicated by the "·" symbol, such that the magnetic field (represented by curved arrows **552**) has a vector in the counter-clockwise direction in accordance with the right-hand rule. The orientation of M2 **562** of the soft-reference layer **514** is therefore oriented-on-the-fly towards the right. As before the magnetic field **552** is quite small and insufficient to affect the orientation of M1 **570** of the data layer **510**.

[0094] The resistance of the Second Known Current I_S (the second resistance, R2) is measured and recorded. With R2 now known, the values of R1 and R2 may be compared, decision **720**. If the initial resistance is greater than the second resistance (R1>R2), a first logic level associated with this first state is returned, block **722**. If the initial resistance is less than the second resistance (R1<R2), then a second logic level associated with this second state is returned, block **724**.

[0095] Under appropriate circumstances, this separate initial current I_R may be applied to flow from the first sense/write conductor **504** through the SVM cell **502** to the second sense conductor **506**. Moreover, in at least one embodiment, for the sensing of resistance within the SVM cell, the direction of the current I_R is substantially immaterial.

[0096] For either method, it is appreciated that where R1 is greater than R2, a first logic level associated with the first state is returned. As a result, under appropriate circumstances the method may be simplified to test for this condition, R1>R2. Further, in at least one embodiment, the measurement of current flow through the SVM cell **502** for the determination of resistance is made according to an integration of time.

[0097] The inadvertent re-orientation of unselected SVM cells is advantageously reduced in write operations. As shown in FIGS 6A and 6B, the reorientation of a selected data layer **510**, will occur when and if the magnetic field **550** of the third write column

conductor **508**, is combined with the magnetic field of the first sense/write conductor **504**, (represented as arrows **600** and **602**). The magnetic field **600, 602** is provided when an appropriate current I_W is provided through the first sense/write conductor **504**.

[0098]   Shown in FIG. 6A, the fields **550** and **600** combine to align M1 **610** of the data layer **510** towards the left. Shown in FIG. 6B, the fields **552** and **602** will combine at to align M1 **612** of the data layer **510** towards the right. In either case, the fields combine at the selected SVM cell **502**, permitting the reorientation of the selected SVM cell **502** while reducing the likelihood of inadvertently switching unselected SVM cells. The orientation of the soft-reference layer **514** is of little concern, for the orientation of M2 will return to a relaxed state (anti-parallel with respect to M1) once the magnetic fields are removed.

[0099]   It is understood and appreciated that a convention will be adopted such as, for example, a logic state of "1" exists where M1 and M2 are anti-parallel (high resistance) in a first state, and a logic state of "0" exists where M1 and M2 are parallel (low resistance) in a second state. It is important to note that the sensing of the initial resistance (the first resistance) may be performed repeatedly, and averaged. So too may the sensing of the second resistance be performed repeatedly, as it is well known and appreciated that with greater sampling there is a reduction in arbitrary error.

[00100]   As the orientation of M2 **560, 562** of the soft-reference layer **514** is being altered in the sense process and not the orientation of M1 **570** of the data layer **510**, a disruption/corruption of the data layer **510** during the read/sense process is substantially unlikely as the data layer **510** is not subjected to any write or re-write operation as is common in the prior art. This non-disruptive sensing ability is most advantageous.

[00101]   Another embodiment may be appreciated to be a computer system incorporating the soft-reference three conductor magnetic memory **200**. A computer with a main board, CPU and at least one memory store comprised of an embodiment of the soft-reference three-conductor magnetic memory **200** as described above raises the advantages of the improved SVM cells to a system level.

[00102]   Changes may be made in the above methods, systems and structures without departing from the scope hereof. It should thus be noted that the matter contained in the above description or shown in the accompanying drawings should be interpreted as illustrative and not in a limiting sense. The following claims are intended to cover all generic and specific features described herein, as well as all statements of the scope of the

present method, system and structure, which, as a matter of language, might be said to fall there between.